

ESD RECORD COPY

RETURN TO
SCIENTIFIC & TECHNICAL INFORMATION DIVISION
(ESTI), BUILDING 1211

Technical Note**1966-38**

**A Study of the Capability
of a LASA
to Aid the Identification
of a Seismic Source**

H. W. Briscoe
R. M. Sheppard

11 July 1966

Prepared for the Advanced Research Projects Agency
under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



ESL

AD0637283

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

A STUDY OF THE CAPABILITY OF A LASA
TO AID THE IDENTIFICATION OF A SEISMIC SOURCE

H. W. BRISCOE

R. M. SHEPPARD

Group 64

TECHNICAL NOTE 1966-38

11 JULY 1966

LEXINGTON

MASSACHUSETTS

ABSTRACT

Several studies have been performed to investigate the ability of a LASA or a network of LASAs to aid in discriminating between explosions and natural earthquakes from observations of the seismic waves they generate.

The major effort has been an attempt to relate the ability to observe the pP phase, first motion, and complexity of an event to the well-documented ability of LASA to improve signal-to-noise ratio. The results indicate that the ability to see first motion varies directly with SNR, but that the ability to identify pP is apparently improved more than the SNR gain would indicate, probably due to the ability of a large array to measure velocity directly. In this study, no quantitative gauge for defining the correct value of complexity has been found; therefore, we made no attempt to estimate a level of improvement for determination of complexity. It appears that complexity can vary widely between different subarrays and, of course, combining subarrays tends to smooth out the variations.

Two experiments designed to take advantage of the high SNR gains available at the lower frequency end of the short-period band (0.1 – 1.0 cps) are in progress. One of these, an attempt to observe S-wave energy on small events, has been hampered by an unexpected and, as yet, unexplained high level of signal distortion. The other study, designed to investigate the pattern of P-wave spectra in the 0.1 to 1.0 cps region, has indicated that the energy in this band may be lower for explosions than for earthquakes, but it is too early in the study to state quantitative results.

One of the most significant contributions of a network of LASAs is seen to be to reduce the large separation between the detection and the identification thresholds by making use of the ability to reprocess weak events off-line.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

I. EVALUATION OF THE IDENTIFICATION CAPABILITY OF A LASA

The ultimate objective of the study reported in this note was to evaluate the capability of a network of Large Aperture Seismic Arrays (LASAs) to separate earthquakes and explosions by observation of the seismic waves they generate. The study includes both a search for new identification criteria that can be observed only with LASAs and an analysis of the capability of a LASA to observe the features presently used for identification of seismic sources using single seismometers or small arrays.

Although no useful new criteria have been found yet, a few possibilities are being investigated. Section III of this report is essentially a progress report on this phase of the study.

At least for the present, however, the discrimination capability of a network of LASAs must be based on the use of the conventional techniques. The most successful features^{1,2} for teleseismic source identification with existing stations are

1. Depth, which is most reliably established by observation of the pP phase,
2. Degree of asymmetry of the radiation pattern, particularly the direction of first motion,
3. Complexity of the P-coda generated near the source,²
4. Relative energy distribution between body and surface waves, usually measured using the "AR" technique.^{3,4}

All of these techniques for separating explosive and natural events now used on the data from small arrays or single instruments require that data be taken at several azimuths relative to the source in order to take advantage of or correct for source radiation

patterns and normal moveout (velocities) of the various phases. For example, determination of the depth for an event requires observation of arrival times at several stations, identification of the pP phase to determine depth is most reliable when the observations are verified by observation of the velocity from the arrival at several widely-separated stations, first motion is essentially a direct measure of the degree of asymmetry of the radiation pattern, and even the AR criterion requires data from several stations both to determine the epicenter for and to correct the effect of radiation pattern on magnitude determination. Since only data from the single LASA in Montana was available for our study, a direct measure of the capability of a network was not possible; and a quantitative evaluation of the Montana LASA has consisted of the measurement of the signal-to-noise ratio (SNR) gains achieved by various array processing techniques.⁵

The principal result of the study discussed here is an attempt to relate SNR gain of a LASA to the resulting ability to observe the waveform features which are used in the conventional discrimination technique listed above. The parameter used in evaluating the LASA is the "magnitude shift," defined as follows. If a measure of the ability of each of two types of stations at the same location to observe a particular waveform feature on a collection of events is plotted against the magnitudes of the events (e.g. a plot of the fraction of events of a given magnitude on which the feature can be observed or not observed), the "magnitude shift" for that feature is the magnitude separation between the two curves and is a measure of the relative capability of that type of station compared with the other. Section II of this report describes an

experiment performed to determine the magnitude shift between a single subarray, which is comparable to the present Vela or UKAEA arrays, and a single LASA.

The capability of the Montana LASA to perform studies in discrimination is not only hampered by the single site limitation, but also by the present lack of long-period and horizontal seismometers. The Montana LASA instrumentation is in the process of being augmented with long-period seismometers which will allow experiments such as those using the "AR" criterion,³ but there are no present plans for addition of short-period horizontal instruments. Experiments to attempt to predict the effect of arrays of long-period instruments are discussed in Section IV. Studies of the possible value of short-period horizontal instruments are also in progress and are discussed in Sections III and IV.

II. OBSERVATION OF CONVENTIONAL IDENTIFICATION FEATURES WITH LASA

The capability of the LASA to improve the signal-to-noise ratio of seismic waveforms has been extensively investigated and documented. It has been shown that delayed sum processing of data from the Montana LASA results in an SNR gain of about 15 db or 0.75 mag. over a single sensor or 12 db or 0.6 mag. over the subarray direct sum trace.⁶ More complex filter-and-sum processing procedures can yield SNR gains as high as 26 db or 1.75 mag. in the P-wave signal band (0.6 – 2.0 cps) for off-line processing.⁵ In order to investigate the relation between the SNR gain and the resulting magnitude shift for observations of various waveform features, an analyst was instructed to read first motion, pP, and complexity for a set of 130 events in two passes. On Pass I he was allowed to see a chart recording containing a side-by-side display of 15 seismometer traces from subarray F4 and the direct sum from subarray F4, and on Pass II he was allowed to use a chart recording containing the direct sums from 15 subarrays and the beam formed by delay-and-sum combining of all 21 subarray sums. The set of events was selected from a library of digital tapes of LASA data, and it included all those events for which delays could be picked from 21 subarray sum traces so that the delay-and-sum beam could be formed. The requirement for picking delays from the direct sum traces has resulted in a bias toward strongly recorded events in the population of events of apparent LASA magnitude 4.0 to 4.5 and a low magnitude cutoff at about LASA magnitude 4.0. The distribution of the set of events in LASA magnitude and in amplitude is shown in Table I. To give an idea of the bias of our

population of 130 events, Table I also shows the relative distribution that would have occurred naturally.

Distribution by LASA Magnitude			Distribution of Amplitude	
<u>Magnitude Range</u>	<u>Number of Events</u>	<u>Natural Distribution of Events*</u>	<u>Amplitude Range (mμ)</u>	<u>Number of Events</u>
3.5 – 3.9	1	725	1.5 – 3	6
4.0 – 4.4	21	155	3 – 6	28
4.5 – 4.9	50	72.5	6 – 12	34
5.0 – 5.4	38	15.5	12 – 24	34
5.5 – 5.9	11	7.25	24 – 48	10
6.0 –	9	1.55	48 – 96	9
			96 – 192	6
			192 –	3

* Expected number of natural events normalized to the observed population between mag. 4.5 and 5.4.

TABLE I
DATA FOR MAGNITUDE SHIFT STUDY

The SNR gain of the beam used in Pass II compared to the direct sum at a single subarray is approximately 12 db or 0.6 magnitude units. Assuming that the only factor affecting the visibility of a specific waveform feature is SNR, the magnitude shift between Pass I and Pass II should be 0.6 magnitude units. Other factors may have

a significant effect on the magnitude shift indicated by this experiment. For example, the analyst may recognize a moveout pattern of the feature over the aperture represented by the 15 subarray sums, or the amplitude scatter may result in the subarray used for Pass I being unusually weak or some other subarray being unusually strong on Pass II for some events.

Before describing the results of this experiment, we should point out that for one conventional discriminant, source location, the LASA capability is not only a function of its S/N improvement, but is a direct consequence of the large aperture. For this feature, a single conventional station has no effective capability, but every event used in this experiment could be (and was) located using data from a single LASA. A review of the LASA station bulletin for one month shows that, out of a population of 445 events and 64 possible events detected at LASA, 296 were located by the single Montana LASA site.

A. Observation of pP

In attempting to identify pP, the analyst assumed that no other depth data would be available, so that any pP phase chosen had to produce a reliable depth estimate. Thus, he tended not to accept bursts of energy less than eight seconds after P onset, and he normally did not use a phase unless it alone stood out in the P-coda in both amplitude and coherence on most of the traces available to him. For example, no pP was accepted for the event in Fig. 1 although consistent appearance of the energy six to seven seconds after P among several stations of a network would be a reliable indication of pP.

The results of the experiment for observation of pP are shown in Fig. 2. Since a large fraction of the events at any magnitude are shallow events, the fraction of events of even large magnitudes for which pP is not found is about 40% to 50%. The points for Pass I can be seen to break upward significantly above this level around magnitude 5.0. The points for Pass II must also break upward at some low magnitude, but they do not break upward within the magnitude range represented in this set of events. The implication of the lack of an upturn in the observations is that restricting the population to events for which arrival times can be picked on 21 subarrays has so severely limited the population of small magnitude events that the magnitude shift for pP cannot be determined conclusively from this data. The data is further limited by the possibility that there is no assurance that the base line should stay constant at around 50% for the weak events. It is conceivable that a larger portion of weak events is shallow.

The aperture of the LASA offers an advantage in addition to SNR gain for identification of pP in allowing a direct measure of the horizontal phase velocity of a detected phase or burst of energy. Thus phases such as PcP which can often be confused with pP on data from a single conventional station can be properly identified at a single LASA station. As a result, an observation of pP at a LASA station is more reliable than an observation from a conventional station. In a sense, the many subarrays of the LASA are providing the same kind of velocity information only obtainable, when using small arrays, from data from globally separated stations. In the experiment

described here, for example, 26% of the observations of strong phases identified as pP on Pass I (14.5% of all events used) disagreed with the best depth estimate available from C. and G. S., but only 13% of the pP observations from Pass II conflicted with the C. and G. S. depth estimates. Moreover, of six faulty pP observations on Pass I data, all but one were corrected on Pass II. In Figure 3 the failure to observe pP is plotted as a function of amplitude instead of magnitude. Each point on this curve contains data from a range of magnitudes so a base line shift with magnitude would tend to be cancelled and the curve should indicate a 12 db shift if SNR gain alone is controlling the shift. The actual shift seems to be greater than 18 db, indicating a probable effect from recognition of the moveout when traces from the full LASA aperture are available. Note that the curve for Pass I in Fig. 3 levels off for low magnitudes at about 85% failure rate confirming that the false alarm rate of about 15% suggested in comparison with C. and G. S. depth.

The results of our magnitude shift study for observation of pP between a conventional array (represented by a single LASA subarray) and the LASA suggest a shift of about one magnitude using a processing technique with a signal-to-noise improvement equivalent to only 0.6 magnitude units.

B. Observation of First Motion

The lack of data from low magnitude events in our experiment has limited the accuracy of the observation of the magnitude shift for first motion as well as for pP. The first motion data, summarized in Fig. 4, suggests a shift on the order of one

magnitude unit, but the reduced slope of the curves between magnitude 4.0 and 4.5 suggests a strong bias toward relatively large amplitude events at the low magnitudes so that this part of the curve is probably not reliable. Figure 5 shows the plot against amplitude, and the amplitude shift of about 15 db suggests that, for first motion, the primary factor affecting the magnitude shift is the SNR gain.

The analyst used coherence of first motion on all traces available to him as a strong factor in acceptance of first motion. In some cases, features with in-band SNR as low as two were used to determine first motion because of their consistent appearance. Figures 6 and 7 show examples of first motion that were considered not reliable and acceptable, respectively. The fraction of cases for which the determination on Pass I data changed on Pass II is only about 6 1/2%, indicating that the criteria were quite strict. A change in the criteria for accepting a determination of first motion should also shift both curves in a similar way so that the indicated magnitude shift would probably not change appreciably if the rules were changed to reduce the false choice rate.

Based on this study we conclude that the magnitude shift for observation of first motion using delay-and-sum processing with the LASA compared to a single subarray is 0.6 magnitude units or greater, and relative SNR gain for other station configurations or processing techniques can be used as a reasonable estimate of the resulting magnitude shift for determination of first motion.

C. Observations of Complexity

The complexity of the seismic waveform arriving from near the source can be masked by in-band background noise or by signal-generated noise or reverberation at the receiver. As a result, a weak event may appear erroneously complex or simple because the P-coda is distorted by noise, or a strong, simple event may appear quite complex as a result of reverberation near the receiver. The LASA may offer a solution to both the problem of reverberation and of low SNR. The signal-to-noise improvement may reduce the noise level so that the coda of a weak event can be seen, as in Fig. 8; or, if the aperture is large enough that the geologic structure controlling the reverberation varies significantly across the array, the reverberation from a large event may be reduced, as in Fig. 9, so that the source complexity is the predominant feature of the coda. Thus an evaluation of the effects of a LASA on the use of complexity would require a study involving data of comparable quality from several azimuths around the source with a large population of events including a reasonable sample of both earthquakes and explosions. In this study, the analyst attempted only to class an event as unusually complex, unusually simple, or average complexity.

A crude indication of the improvement in the ability to analyze complexity using a LASA may be the number of events on which the complexity estimate changed on Pass II. In this study, out of a total of 130 events, 18 events appeared to have a significant change in complexity between Pass I and Pass II, and four more were not visible on Pass I.

D. Additional Observations on Very Weak Signals

A more unbiased population of events for a magnitude shift study should include events located, and possibly even detected, using data from more than a single site so that more small events would be used to correct the bias illustrated in Table I. In such cases, the recorded tapes from the LASA would be reprocessed to bring out the signal from the event, and the processing techniques allowed for this off-line analysis would include more effective operations⁵ than the simple delay-and-sum processing allowed in the experiment described above. Although a thorough experiment has not been conducted, a few examples of the results of processing very weak events are available.

One example of such an event is shown in Fig. 10. This event, which had a LASA magnitude estimated at 3.5, is discussed in more detail in Reference 5. It is sufficient here to point out that the complex nature of this very weak event is readily observed after processing, but even the initial P is lost on individual seismometers.

Figure 11 shows typical individual seismometer recordings of an event of C. and G. S. magnitude 3.7 that was one of a sequence of shocks from Rat Island. The LASA magnitude was about 4.0. Figure 12 shows maximum-likelihood processed traces from seven subarrays and the delay-and-sum combination of these seven processed traces. The event is barely detectable on individual traces, but the processed data shows it to be a simple event and also shows pP.

In both of these cases, only the best subarrays were used. In the first case the signal was only strong enough to be found on two subarrays, and in the second case the

local noise level at the 14 subarrays not used was so high that the S/N gain of the processing was insufficient to extract the signal. Such variations⁵ in conditions across the array are not unusual, and it appears that one of the significant advantages of a LASA is that the signal response and noise level at a single subarray or conventional array will vary widely from event to event, but usually the conditions for at least one subarray in a LASA will be favorable to the detection and analysis of each event.

The capability of a single LASA to aid in observing waveform features used for discrimination may be better analyzed by attempting to identify or at least locate and extract a waveform for every event detected by LASA for some period of several weeks or a month. Although such an experiment is planned using the Montana LASA, it has not been possible yet because of personnel and processing capability limitations on-site. Such an experiment is not expected to produce any significant new results, but it should provide more accurate and complete data to document the identification capability of a single LASA, particularly at low magnitudes.

III. STUDIES OF POTENTIAL NEW DISCRIMINANTS

In some ways the LASA offers an instrument for completely new classes of seismic measurements. It is always possible that this new capability will lead to some unexpected measurement of discrimination features that cannot be observed with other forms of station. Several studies are being conducted to explore the possibility of new identification features, but nothing new has been found yet. The status of these studies is summarized in this section.

One of the most impressive results of array processing experiments is the extremely high signal-to-noise gains achievable with filter-and-sum processing in the low frequency band normally masked by microseismic noise (0.1 to 1 cycle). See for example, Figs. 13 and 14 in Reference 5. It would appear that a LASA offers the first reasonable opportunity to observe body wave energy on small teleseisms in this frequency band. Two studies have been undertaken to investigate the use of this frequency band.

A. S-Wave Studies

The first study was an attempt to observe S-energy on short-period arrays. This study made use of short-period vertical component array data from LASA and a three-component short-period array data from TFO. Since S-waves are polarized transversely to the propagation path, the signal in the vertical seismometer will be at least 5 db below that in the horizontals. This factor combined with high attenuation of S-wave energy at short periods makes detection of S-waves on an array of short-period

vertical seismometers unlikely. Even with short-period horizontal seismometers, the array gain may not be sufficient to balance the attenuation along the path, so that detection of S-energy on most events may be marginal.

Our experiments with detection of S-energy on LASA data started with two unsuccessful attempts to find S-waves at the low frequency (0.1 – 0.6 cps) end of the short-period spectrum using sample large events on which no S energy could be found on raw traces. We then processed data from an earthquake in which unusually high frequency S energy (in the normal P-wave band around 1 cps) could be seen on individual seismometer data. The resulting noise suppression in the latter case was on the order of 13 db as is expected for wide-band processing, but the signal loss was 8.3 db, an unusually high loss compared to the 1 or 2 db normal for P-energy. Signal losses of 4 to 8 db were also observed on both vertical and horizontal data when two events from the TFO array including three-component instruments were processed (the horizontals were treated as two separate arrays, one using NE-SW seismometers and the other using NW-SE data). If the signal distortion can be related to amplitude variations or to travel time anomalies, it may be possible to determine station corrections which would correct the distortion of the processed traces and make S-wave observation potentially possible at teleseismic distances using array processing. The possible use of time or amplitude equalization and the use of larger subarray diameters are being investigated.

B. P-Phase Sonograms

The second study is directed at spectral analysis of P and P-coda for explosions and earthquakes. This study is just beginning and the limited data available indicates that conclusive interpretation of the data will not be possible until the programs being used are modified to correct the data for the rapid fall-off of the response of the short-period seismometers in the low-frequency band. The programs being used present the processed data as "sonogram" plots. The sonogram is a three-dimensional plot on which frequency and time are represented by displacement parallel to the Y and X axes, respectively, and the energy at each point in time and frequency is represented by the density of the plot. Thus the pattern of energy distribution in time and frequency is presented for each event. Sonograms from one explosion and three simple earthquakes computed from delay-and-sum beams are presented in Fig. 13. These samples are typical of the three explosions and seven earthquakes that have been run to date. It appears from this limited sample that the low-frequency P and P-coda energy (the bottom five to 10 lines of density plot in the sonograms) from the explosion may be somewhat lower than from many of the earthquakes when compared to the peak energy in the same event.

C. New Measures of Complexity

Another possible important gain with a LASA is the potential ability to suppress reverberation by combining data from sensors in different geologic environments. This could make the source complexity of an event more apparent and may

contribute to the magnitude shift in observation of pP. An attempt was made to find a complexity measurement that would best take advantage of the possibility of suppressing reverberation in favor of source complexity.

An investigation was carried out to measure the degree of complexity of the teleseismic signals arriving at the LASA array in a somewhat unusual way. It was hoped that because of the wide separation of the F ring subarrays a form of processing could be developed which would include in the complexity measurement the part of the coda that was common to two subarrays while rejecting local crustal reverberation which should differ from one subarray to another. The form of processing that was developed multiplies together the envelopes of the bandpassed delayed sums of two subarrays to give a trace from which the complexity was computed. This method of computing complexity is similar to that used by the British, but differs in the fact that the envelopes are formed before multiplying the two terms together rather than afterward, and in that the trace analogous to the British corologram has the dimensions of (amplitude)² rather than amplitude.

This algorithm for computing complexity has been applied to data from three explosions and nine earthquakes using the four F-ring subarrays in order to investigate the affect of the large aperture of LASA. The results show that the processing using cross correlation between two subarrays does not, for a given event, give values of complexity which are greatly different from those computed using autocorrelation of a single subarray. It has, however, become apparent that for some events this complexity of the signal can vary greatly at different subarrays.

IV. ADDITIONAL INSTRUMENTATION FOR LASA

Three-component long-period seismometers are now being added to the center of each subarray of the LASA. When these instruments are in operation, the ability of array processing techniques to extract long-period surface waves can be evaluated. The result may indicate that the AR criterion for discrimination of explosive events could be applied at larger distances from the source by using arrays of long-period seismometers.

Capon, et al⁵ have described an attempt to anticipate the problems involved in the use of long-period seismometers in LASA by processing data from the extended TFO array. It was found that the SNR gain was very close to the \sqrt{N} level expected from N traces with independent noises. The limiting noise may, however, have been associated with the telemetry or recording system and not the seismic noise.

Some consideration has been given to replacing the short-period vertical seismometers in the 500-foot holes at the center of each subarray with three-component short-period instruments, and an experimental installation is in operation in the D2 subarray. This modification would make it possible to apply the REMODE class of processing⁷ to LASA data to aid in detection of pP, and it may make detection and analysis of S phases possible. The S-wave study discussed in Section III included the use of three-component short-period data from the 10 kilometer cross array at TFO.

V. COMMENTS ON THE USE OF A NETWORK OF LASAS

For this discussion, a LASA does not necessarily mean an array identical to the existing LASA in Montana, but to any array that meets the following requirements:

- (1) The aperture of the array is large enough to allow source location from the single array,
- (2) The number of sensors is large enough to provide significant SNR gain,
- (3) The array instrumentation includes sufficient on-line processing capability to perform detection and source location within several minutes after the energy from the event arrives at the site,
- (4) Data from the entire array is recorded with a large dynamic range and relatively wide bandwidth in a form, such as digital magnetic tape, which makes it readily accessible for off-line look-back processing.

It is further assumed that the stations in the network are interconnected by a low-rate round-robin communication net so that it is possible for all stations in the net to learn of an event detected at any one of the stations within 10 to 20 minutes of the detection, that the recordings at each station have a life of about 20 minutes before they are written over, and that event tapes have a life of several weeks. Thus, all recordings containing events detected at any of the network stations can be removed from the transport or explicitly saved by some other technique.

All of the processing used in the magnitude shift experiment described in Section II of this report is simple enough to be performed on-line at an operational LASA. The detection threshold of a station is expected to follow the SNR gains

achieved on-line, and the results described in Section II indicate that the ability to observe the waveform features commonly used for discrimination improves at least that much or more with the proposed on-line processing. Techniques available for the off-line or look-back processing can attain SNR gains significantly greater than the techniques available on-line, and the peculiar characteristics of unusual events (such as the frequency content of the event shown in Fig. 10)¹ can be determined and accounted for in the off-line processing. Thus, for a network of LASAs, the ability to reprocess the recordings off-line for events that are barely detected or even detected only at another site and the ability to use very sophisticated processing techniques not practical on-line should make multiple site coverage of politically or logistically inaccessible areas possible, and should reduce the large gap between the detection and the identification thresholds.

REFERENCES

1. J. DeNoyer, "Identification of Earthquakes and Underground Nuclear Explosions by Seismic Methods," Institute for Defense Analyses, Washington, D. C., Paper P-19, May 1963.
2. E. W. Carpenter, "Teleseismic Methods for the Detection, Identification, and Location of Underground Explosions," Vela Seismic Information and Analysis Center, University of Michigan, Ann Arbor, Michigan, VESIAC Special Report 627, April 1964.
3. J. N. Brune, et al, "Relative Excitation of Surface Waves by Earthquakes and Underground Explosions in the California-Nevada Region," J. Geophys. Res., 68, 1963, p. 3501.
4. R. C. Liebermann, et al, "Excitation of Surface Waves by the Underground Nuclear Explosion Long Shot," Jour. Geophys. Res. (submitted for publication).
5. J. Capon, et al, "Off-Line Signal Processing Results for the Large Aperture Seismic Array," M.I.T., Lincoln Laboratory Technical Note 1966-37, July 1966.
6. E. J. Kelly, "LASA On-Line Detection, Location and Signal-to-Noise Enhancement," M.I.T., Lincoln Laboratory Technical Note 1966-36, July 1966.
7. C. M. Mims and R. L. Sax, "Rectilinear Motion Detection," paper presented at Seismological Society of America meeting, St. Louis, April 1965.

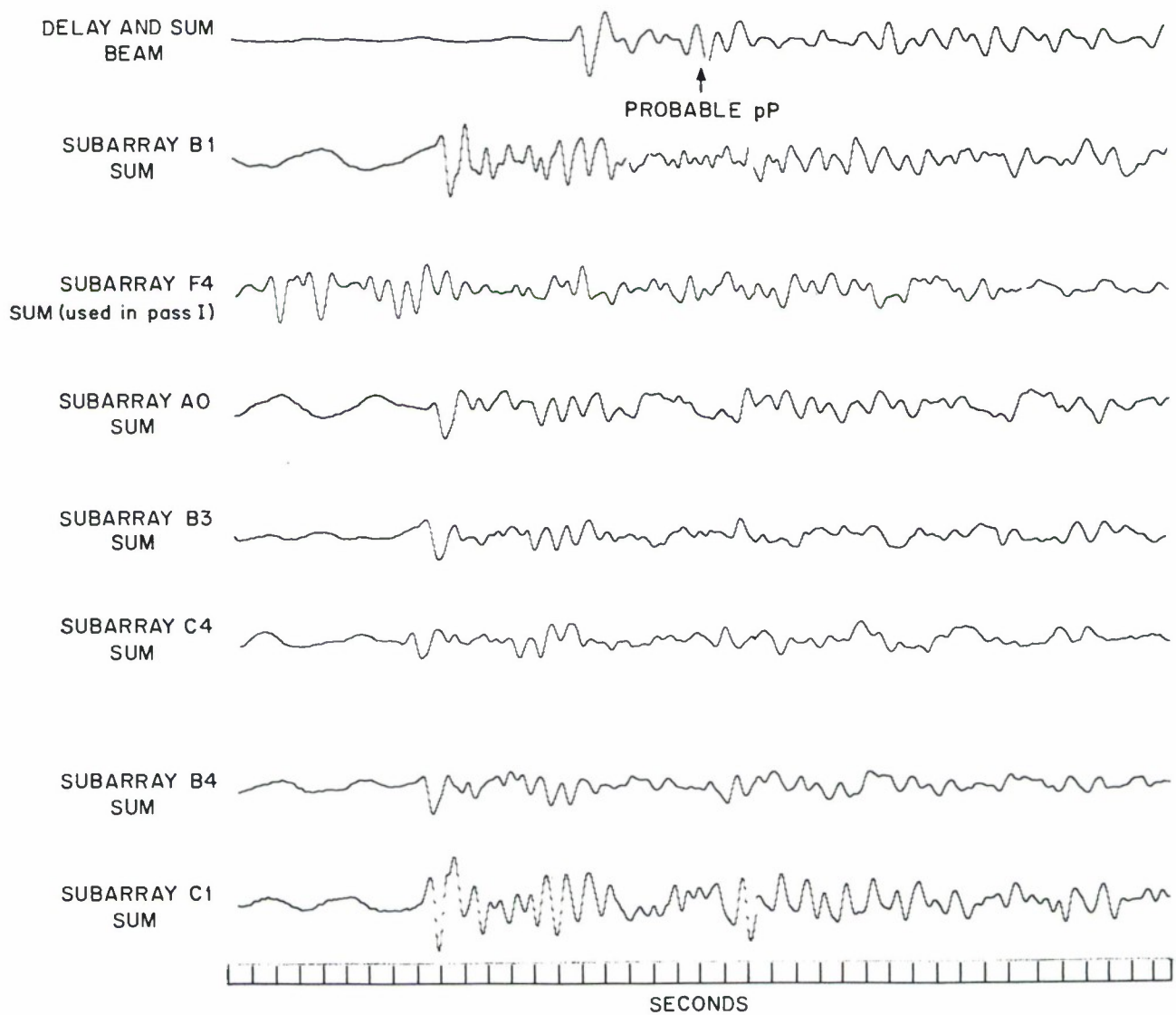
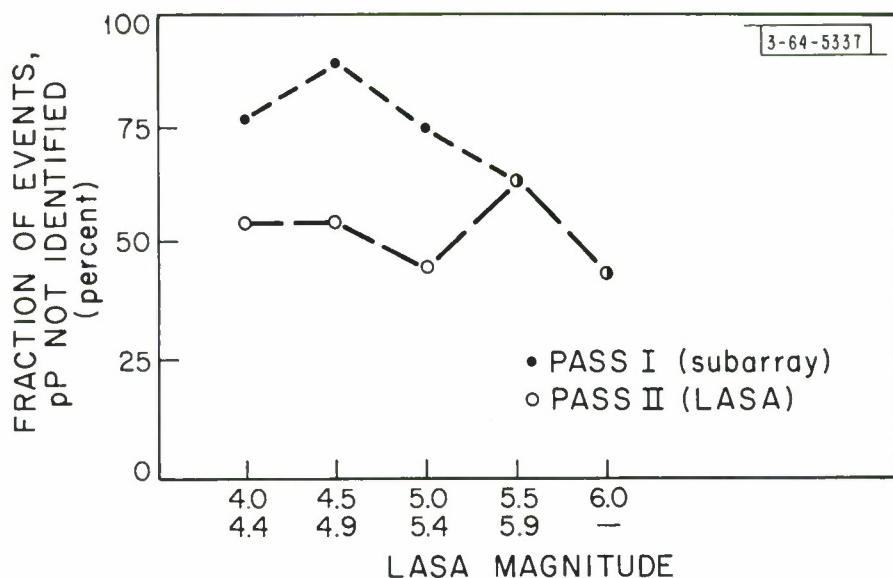
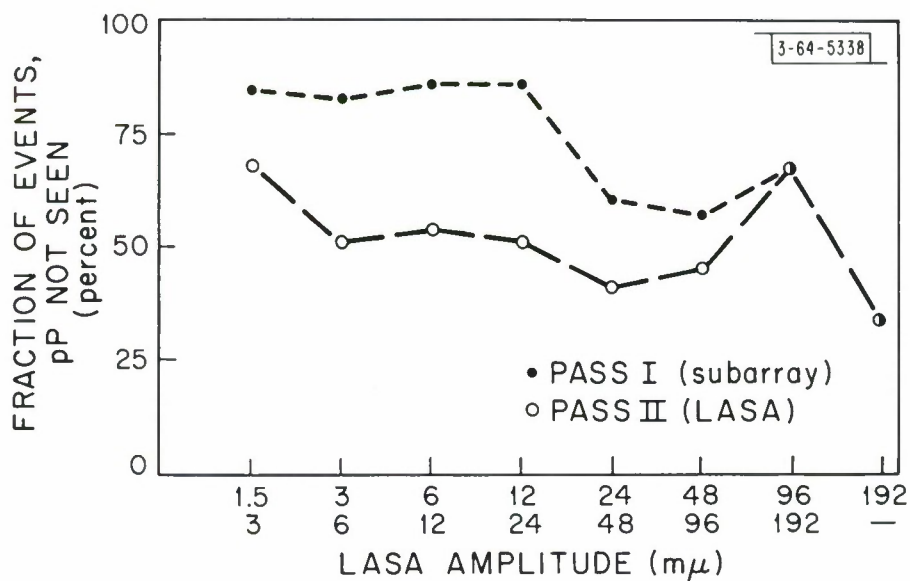


Figure 1. Sample event on which pP could not be picked reliably.



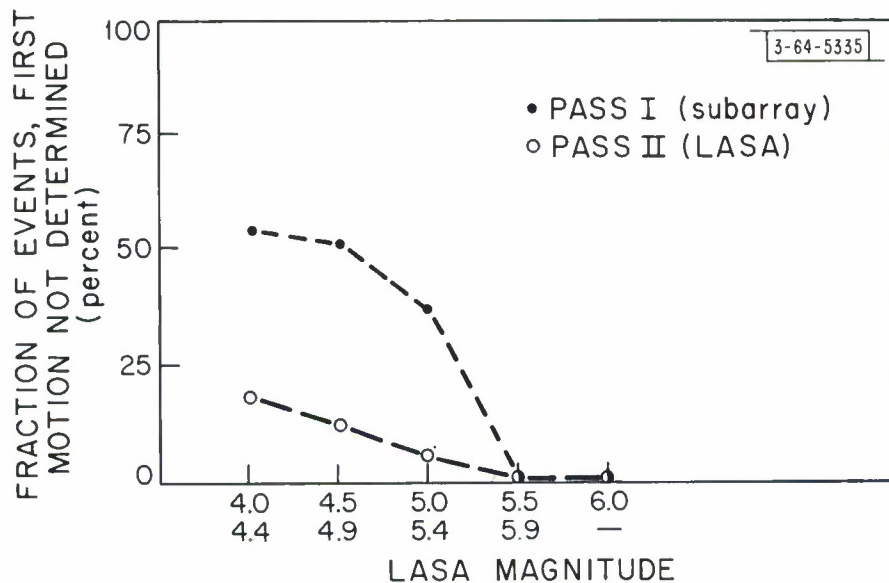
LASA pP STUDY

Figure 2. Fraction of events within each magnitude range for which pP could not be identified.



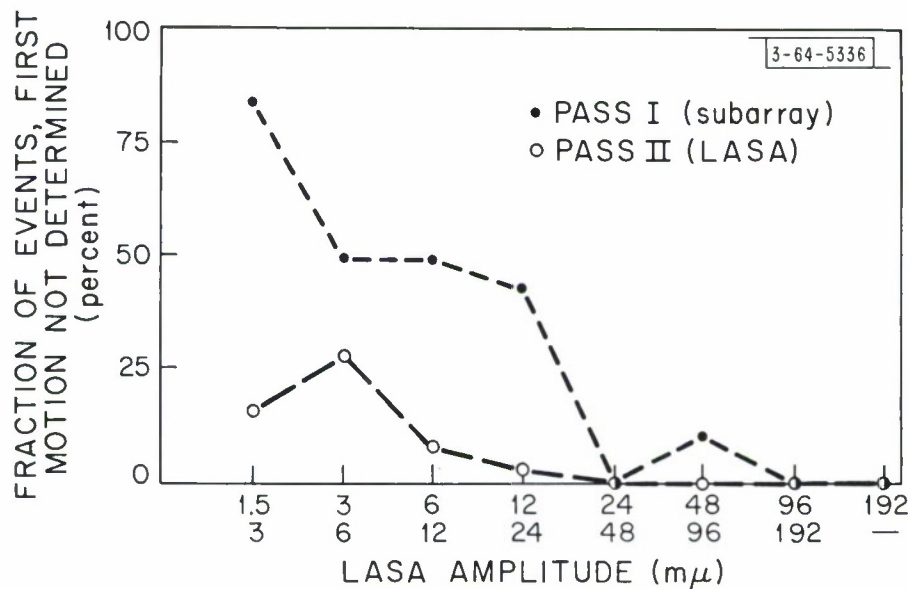
LASA pP STUDY

Figure 3. Fraction of events within each amplitude range for which pP could not be identified.



LASA FIRST MOTION STUDY

Figure 4. Fraction of events within each magnitude range for which first motion could not be read reliably.



LASA FIRST MOTION STUDY

Figure 5. Fraction of events within each amplitude range for which first motion could not be read reliably.

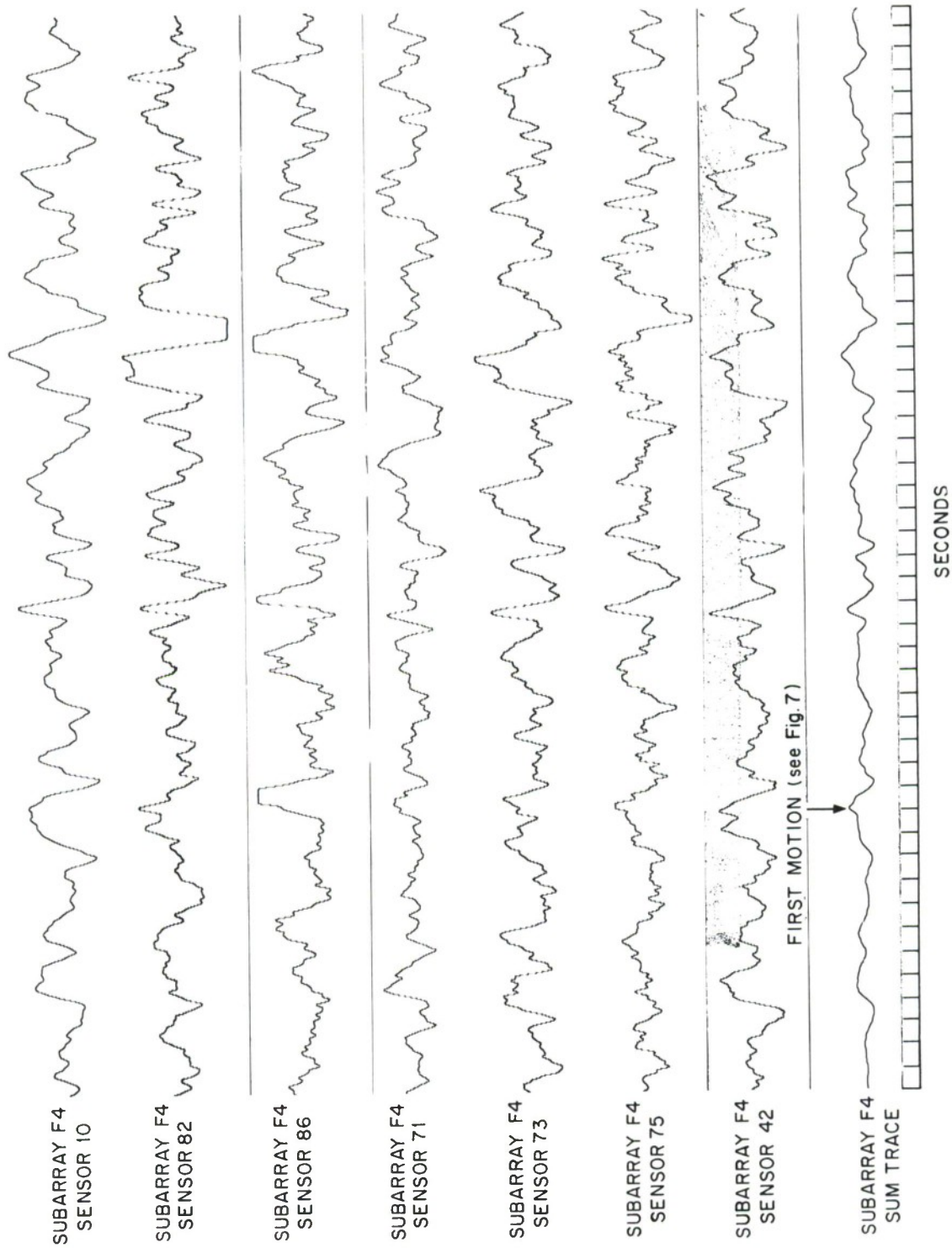


Figure 6. Sample seismogram on which first motion could not be read reliably.

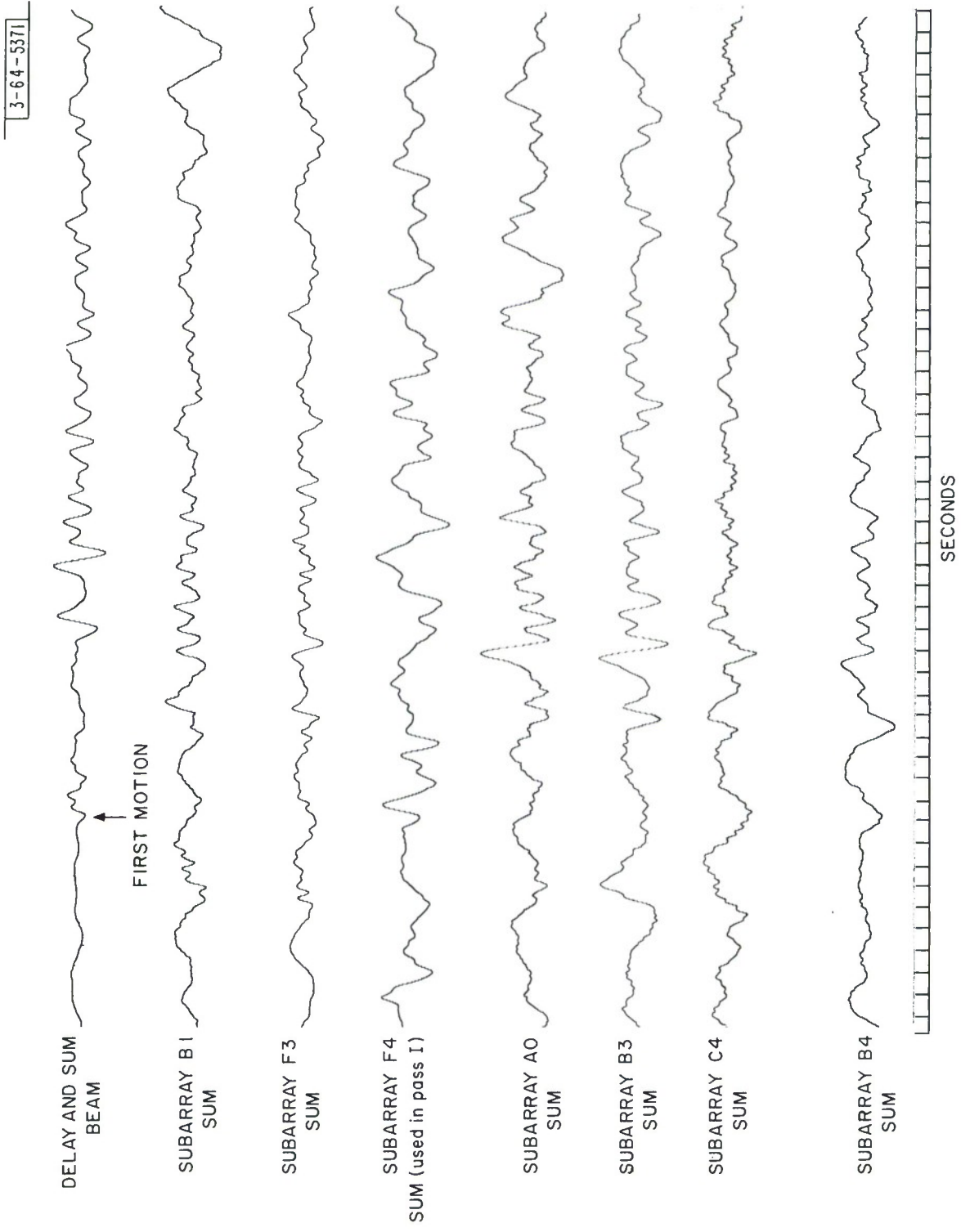


Figure 7. Sample event showing acceptable upward first motion.

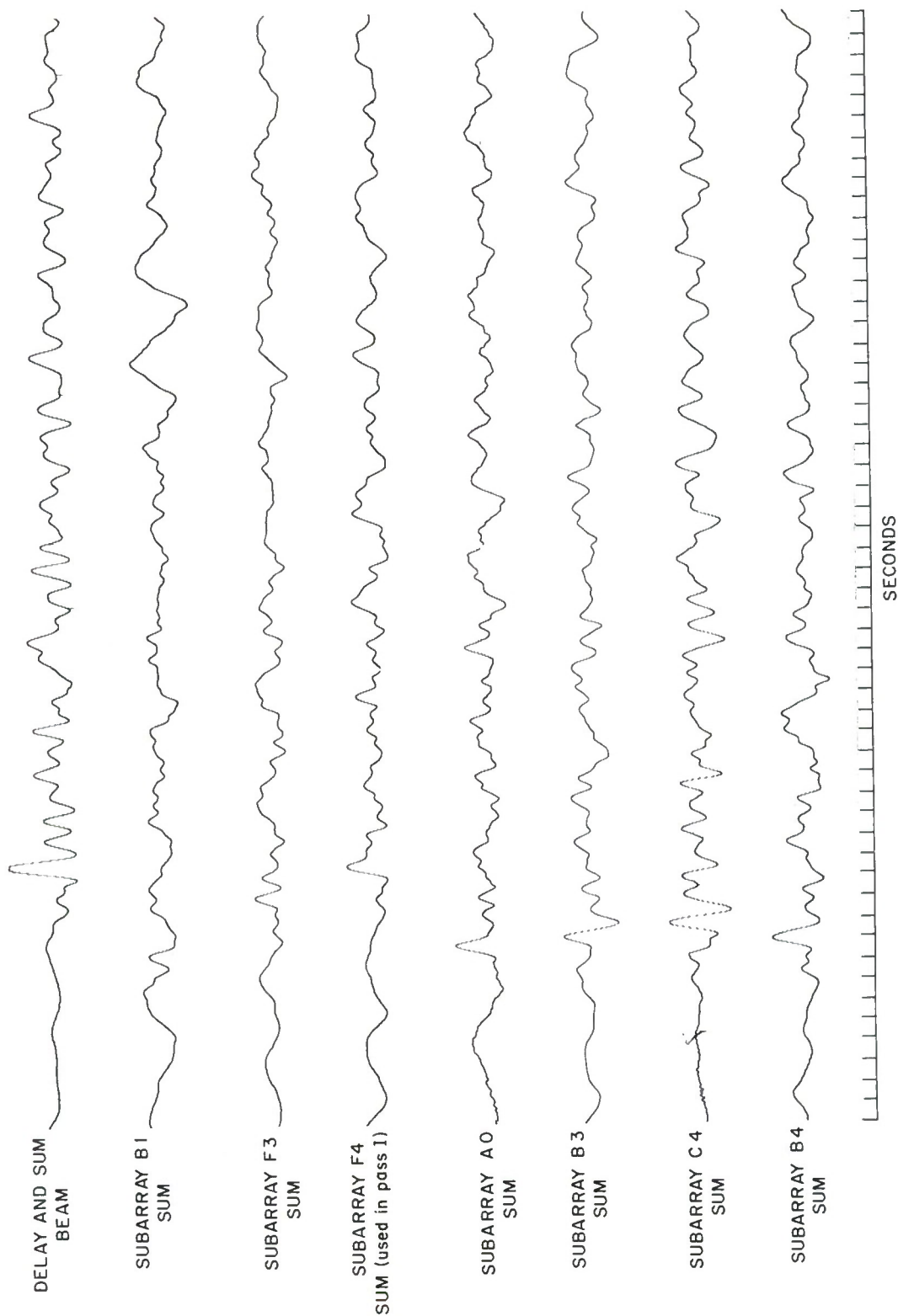


Figure 8. Sample seismogram showing the ability of LASA processing to extract P-coda on an event from background noise. Top trace is the processed data.

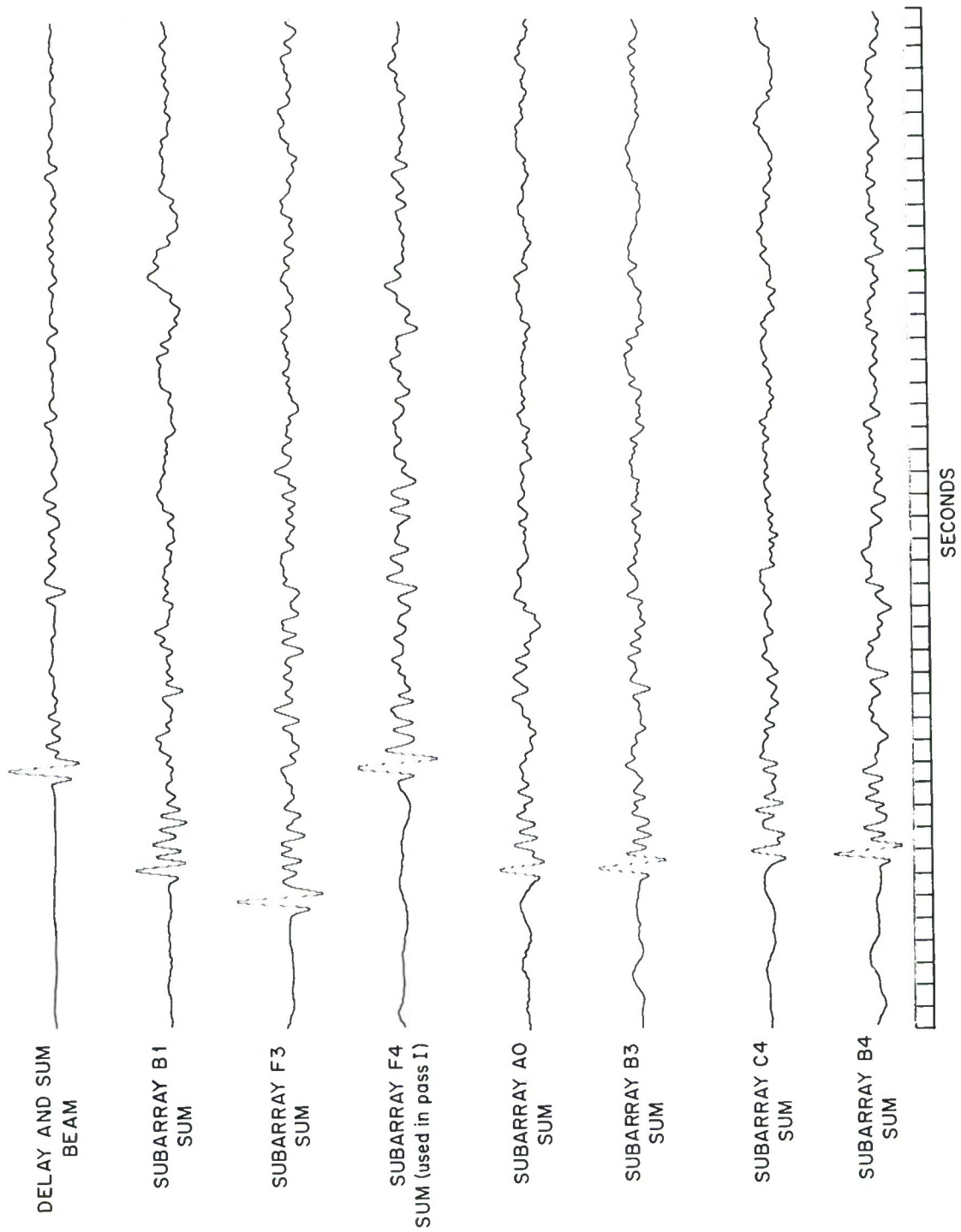
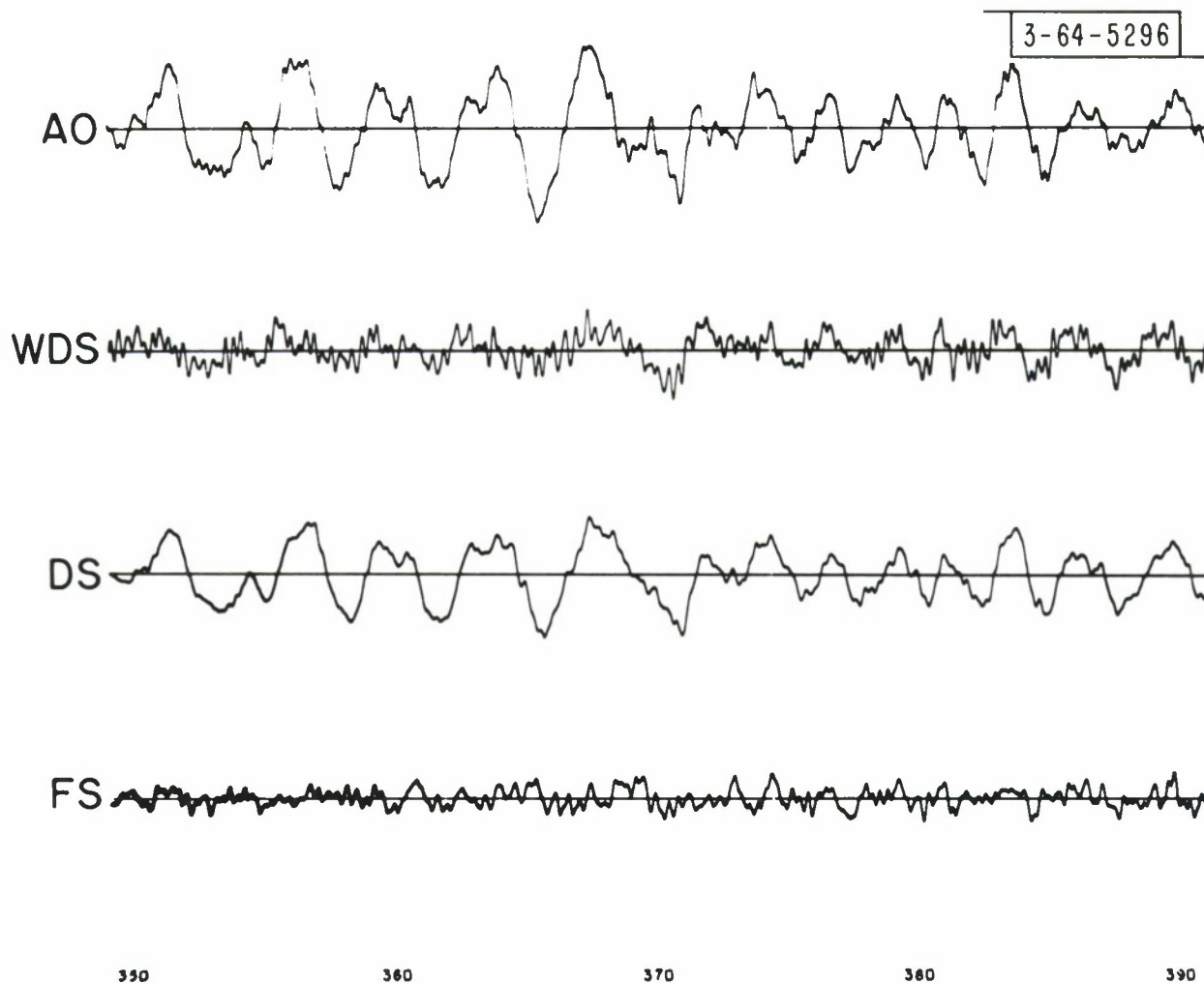


Figure 9. An example of the ability of LASA to suppress reverberation in the P-coda of an event. Top trace is the processed LASA trace.

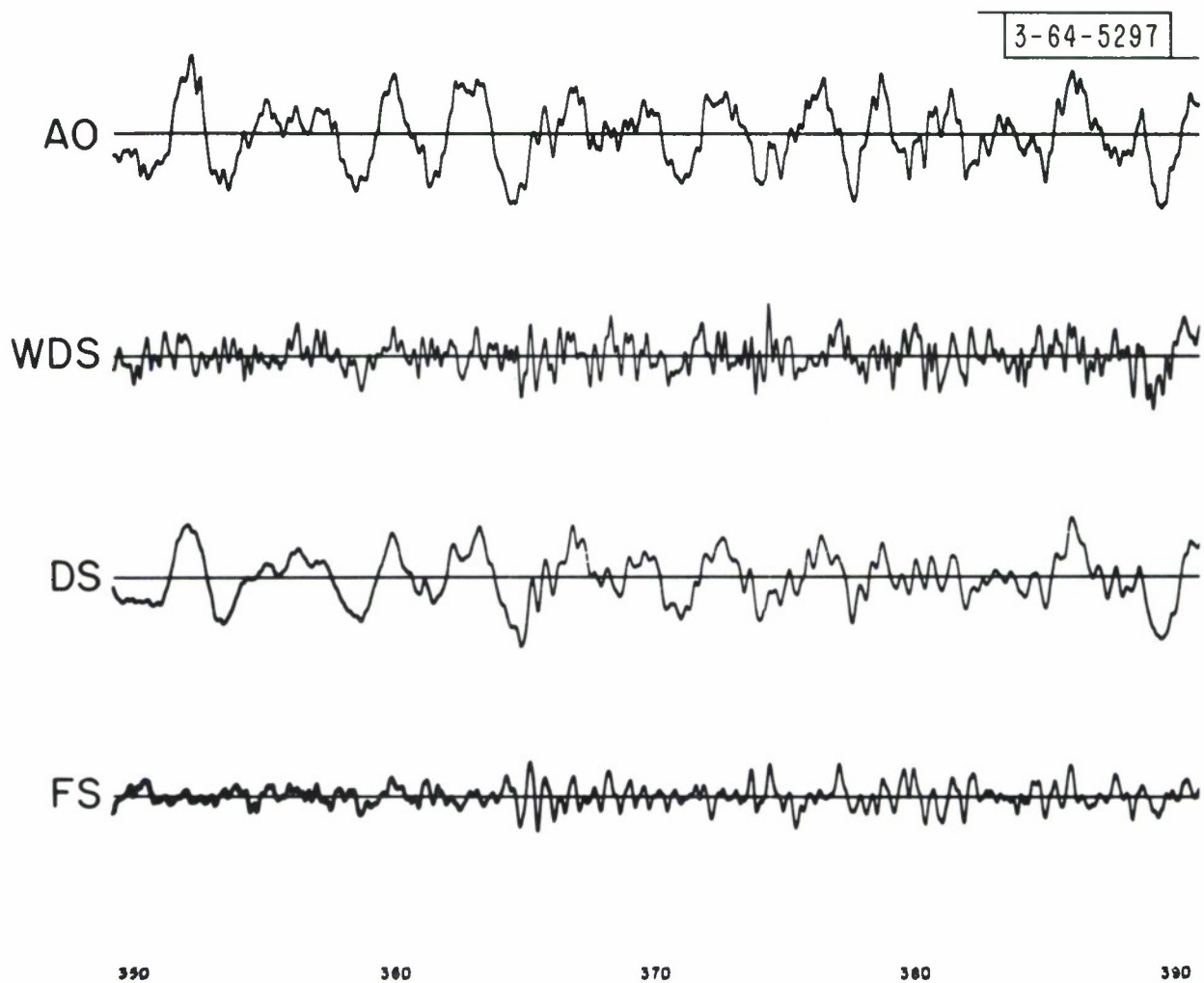


B3

12/11/65 COMMANDER ISLAND EVENT SITE 5

(a)

Figure 10. Results of processing an event invisible on single traces (Commander Islands, December 11, 1965). a. typical sub-array, b and c. two best subarrays, d. results of combining two best subarrays. No prefiltering used. Note visibility of event complexity after processing.



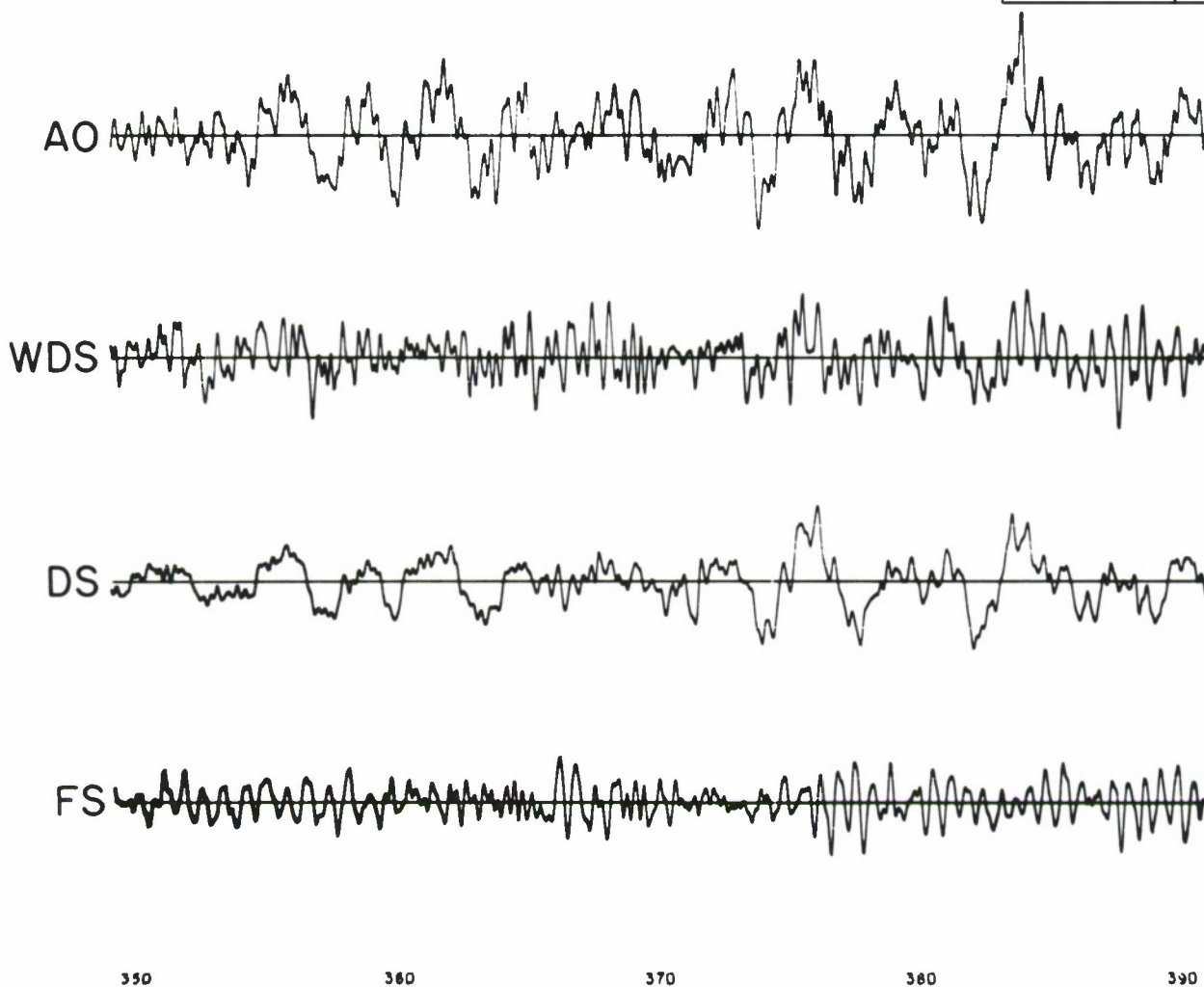
C3

12/11/65 COMMANDER ISLAND EVENT SITE 11

(b)

Figure 10 Continued.

3-64-5298

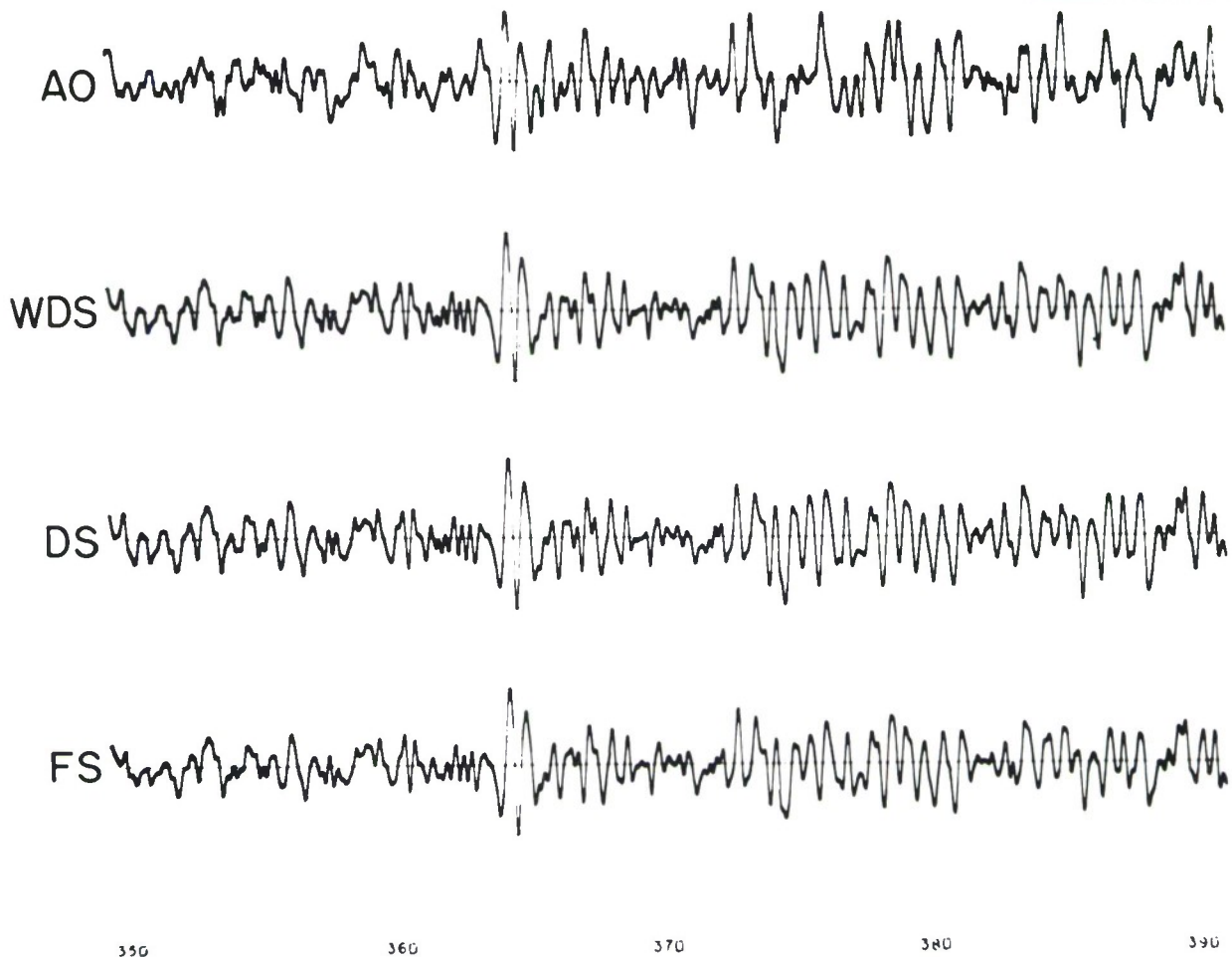


D2

12/11/65 COMMANDER ISLAND EVENT SITE 15

(c)

Figure 10 Continued.



STACK OF C3 AND D2

12/11/65 COMMANDER ISLAND EVENT

(d)

Figure 10 Continued.

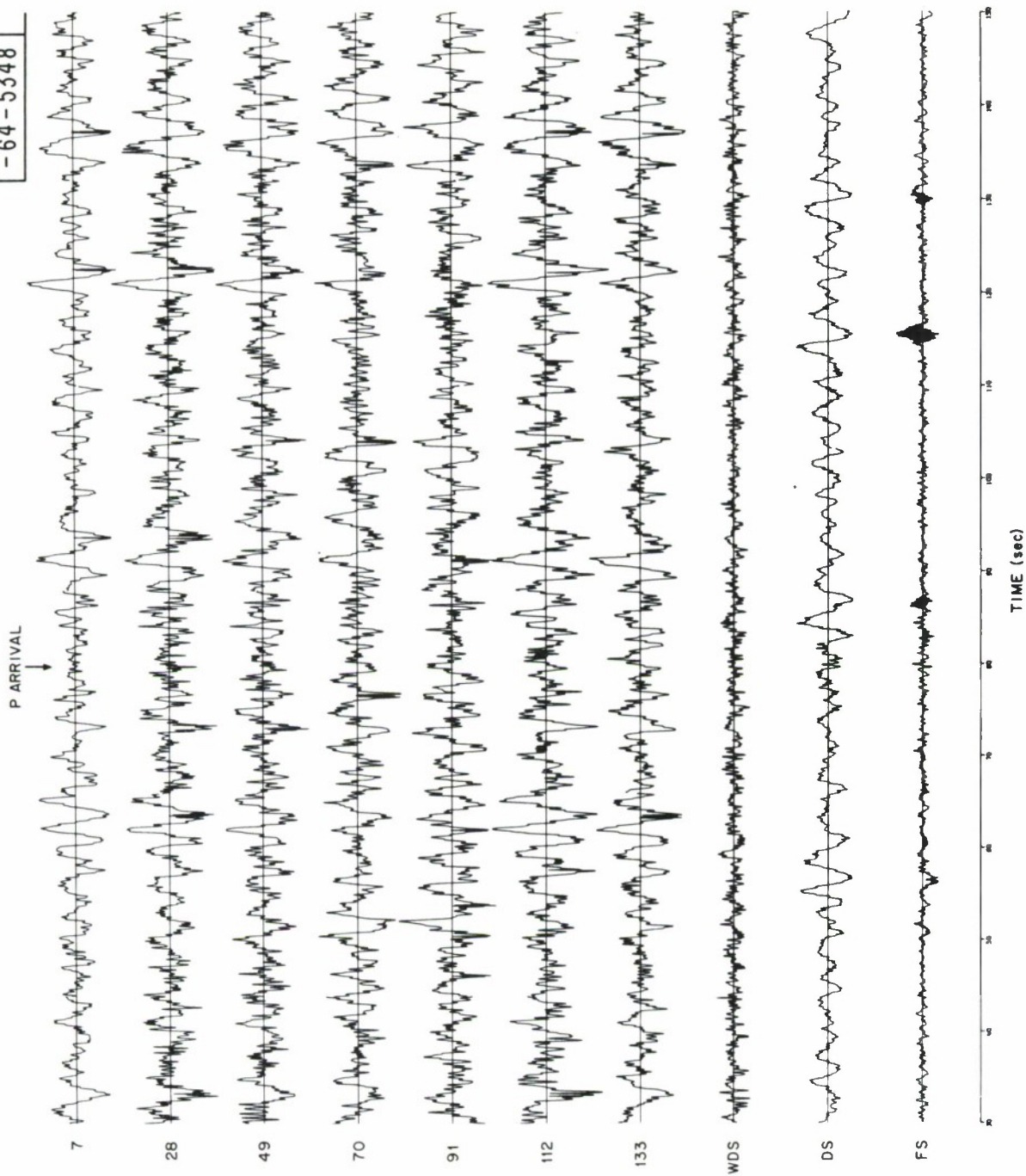


Figure 11. Weak October 1, 1965, Rat Island event before processing.
Subarray B4. Seven sensor output traces and three processed traces.

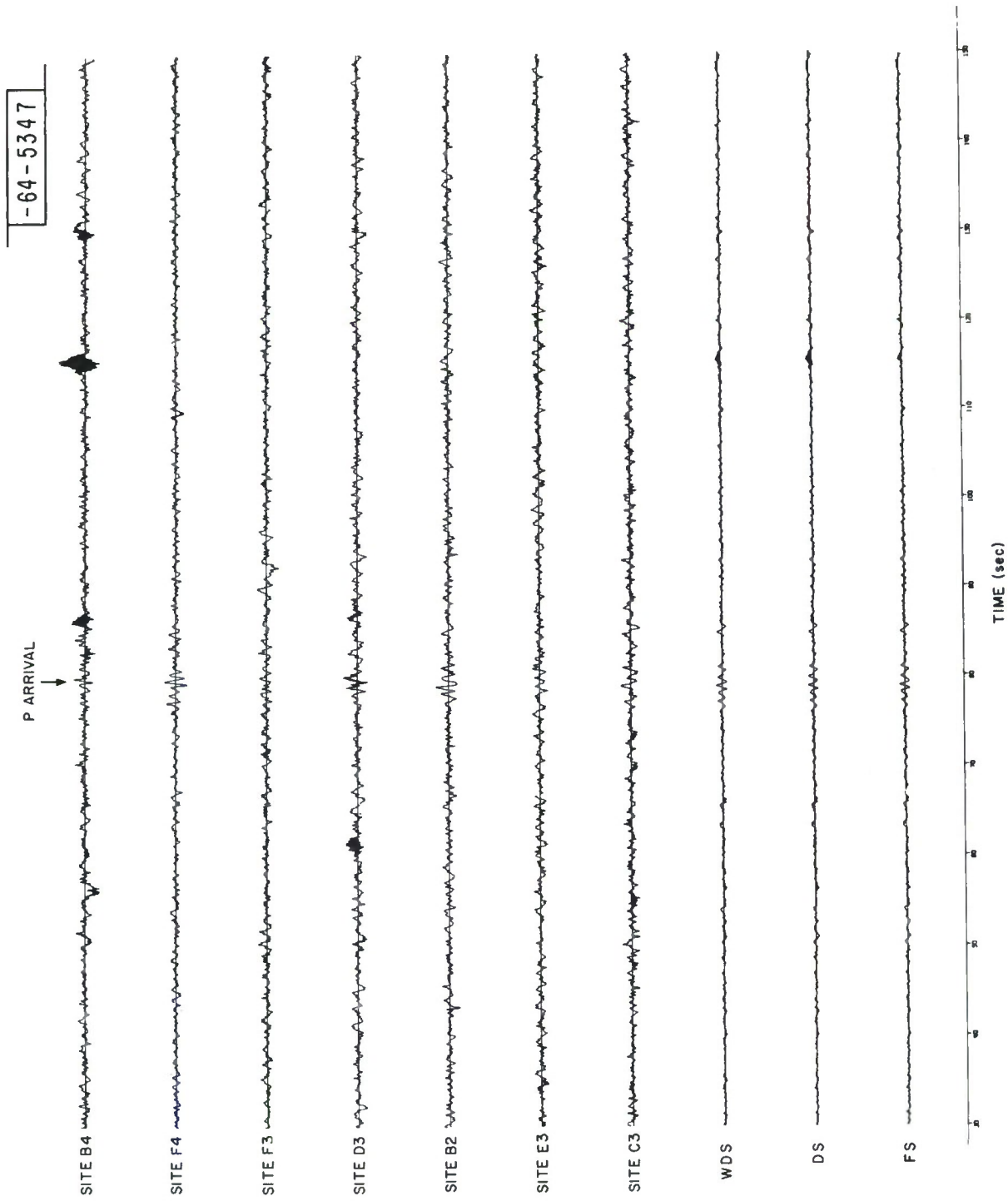


Figure 12. Same event after processing of seven best subarrays. Note pP phase 8 seconds after P.

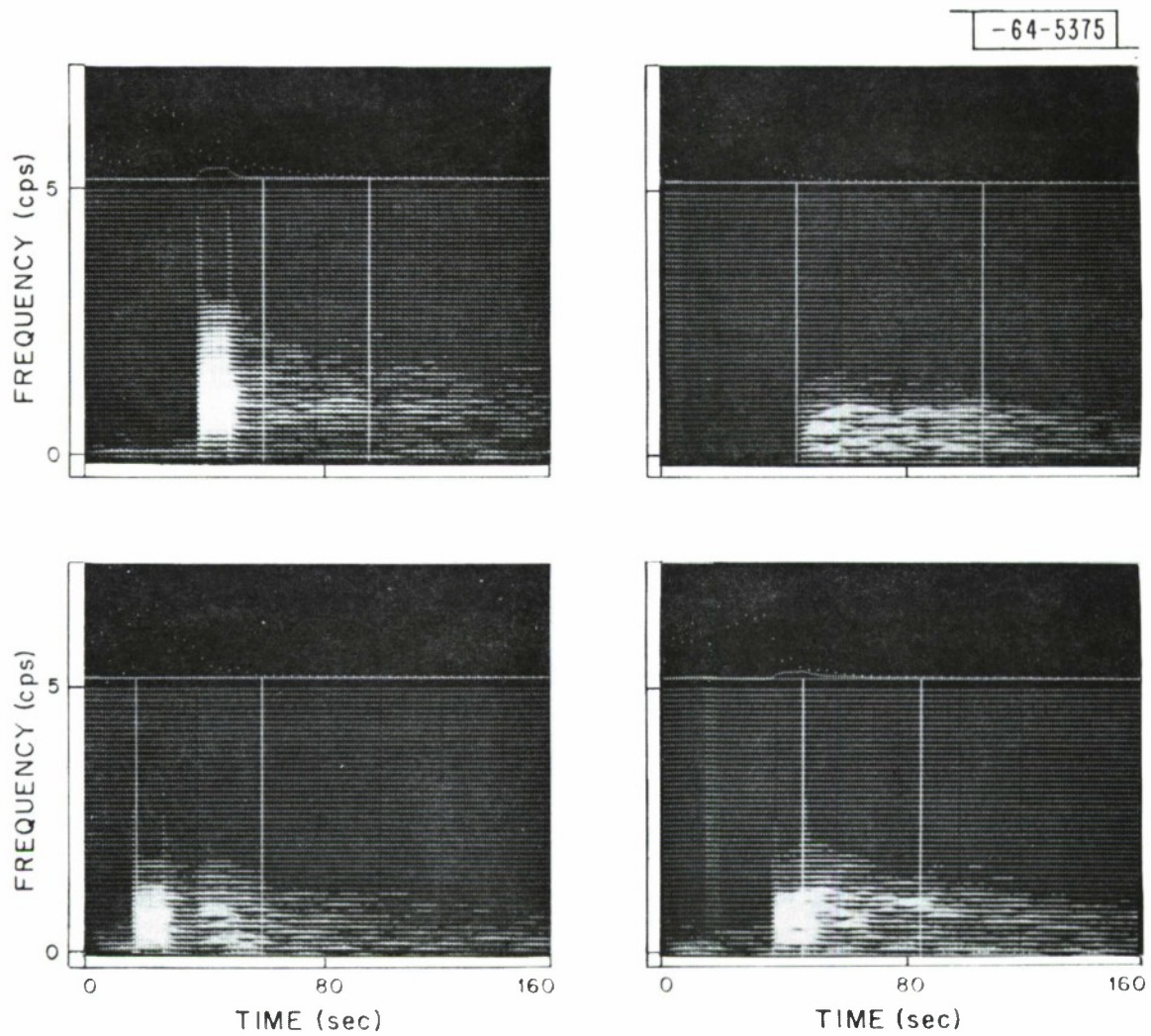


Figure 13. Sample sonograms from an explosion (upper left) and three earthquakes. Note pP phase about 20 seconds after P onset in the event at the lower left.

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION
Lincoln Laboratory, M. I. T.		Unclassified
		2b. GROUP
		None
3. REPORT TITLE		
A Study of the Capability of a LASA to Aid the Identification of a Seismic Source		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
Technical Note		
5. AUTHOR(S) (Last name, first name, initial)		
Briscoe, Howard W. and Sheppard, Robert M.		
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
11 July 1966	40	7
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)	
AF 19(628)-5167	Technical Note 1966-38	
b. PROJECT NO.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
Order 512	ESD-TR-66-362	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES		
Distribution of this document is unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY
None		Advanced Research Projects Agency, Department of Defense
13. ABSTRACT		
<p>Several studies have been performed to investigate the ability of a LASA or a network of LASAs to aid in discriminating between explosions and natural earthquakes from observations of the seismic waves they generate.</p> <p>The major effort has been an attempt to relate the ability to observe the pP phase, first motion, and complexity of an event to the well-documented ability of LASA to improve signal-to-noise ratio. The results indicate that the ability to see first motion varies directly with SNR, but that the ability to identify pP is apparently improved more than the SNR gain would indicate, probably due to the ability of a large array to measure velocity directly. In this study, no quantitative gauge for defining the correct value of complexity has been found; therefore, we made no attempt to estimate a level of improvement for determination of complexity. It appears that complexity can vary widely between different subarrays and, of course, combining subarrays tends to smooth out the variations.</p> <p>Two experiments designed to take advantage of the high SNR gains available at the lower frequency end of the short-period band (0.1 - 1.0 cps) are in progress. One of these, an attempt to observe S-wave energy on small events, has been hampered by an unexpected and, as yet, unexplained high level of signal distortion. The other study, designed to investigate the pattern of P-wave spectra in the 0.1 to 1.0 cps region, has indicated that the energy in this band may be lower for explosions than for earthquakes, but it is too early in the study to state quantitative results.</p> <p>One of the most significant contributions of a network of LASAs would be a reduction in the large separation between the detection and the identification thresholds by making use of the ability to reprocess weak events off-line.</p>		
14. KEY WORDS		
<div style="display: flex; justify-content: space-between;"> <div> LASA seismic discrimination </div> <div> seismic array seismology </div> </div>		